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Location-Aware Wireless Emergency Alerts

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***Abstract*—The Wireless Emergency Alert (WEA) service allows short text messages to be broadcast to all capable mobile devices in a specified geographic area. Although it enjoys nationwide reach, the current WEA service has limitations that impede its public acceptance. These limitations include imprecise geographical targeting of alerts, which reduces the alerts' relevance to many recipients, increasing the likelihood of these recipients to opt out of receiving alerts or stop paying attention. The growing capabilities of smart phones, such as improved location awareness and increased computing power, provide opportunities to alleviate the limitations by personalizing targeted alerts and allowing optimized alert delivery decisions. Motivated by these opportunities, we designed and developed a prototypical, enhanced end-to-end WEA service that includes an alert creation subsystem, a message delivery subsystem, and a smart phone application for capturing, processing, and presenting simulated alerts to recipients. We conducted two public trials with over 225 subjects to evaluate several WEA enhancements using this service. The evaluated enhancements included (1) augmenting WEA messages with high-information maps, (2) precise geographical targeting of alerts, and (3) use of the recipient's location history to influence the alert delivery decision. Our results suggest significant added value for all three enhancements, making them worthy of consideration for future WEA implementations.**

I. Introduction

The Wireless Emergency Alerting (WEA) service is part of the Integrated Public Alert and Warning System (IPAWS) of the Federal Emergency Management Agency (FEMA). It provides a dissemination path for alert and warning messages [1]. Authorized officials can send short text alerts to the public on WEA-capable mobile devices via the SMS Short Message Service Cell Broadcast (SMSCB) protocol, a one-to-many channel for 90-character text messages. Messages are geographically targeted and sent to cell towers covering an affected area, and are subsequently delivered to mobile subscribers. A sample WEA message is shown in Fig.1. The density and range of cell towers vary and the ranges overlap, however. Anecdotally, wireless carriers are opaque about how they map an alert region (for example specified by a polygon) to a set of cell towers, but even with more openness about the used targeting mechanisms, precise geographical targeting is simply not possible with cell broadcast technology alone.

Today's smart phones have network-based mapping capabilities and integrated Geographical Positioning System (GPS) receivers. Built-in maps are expected to be standard in future smart phone generations. These capabilities allow the delivery decision to be made on the phone, provided that a specification of the alert region, or the *geo-target* of the alert, is embedded in the alert message. Such client-side *geo-filtering* can be

Fig. 1: Sample WEA Message

combined with high-information maps to give the recipient visual cues that are easily assimilated. This combination has the potential to address the opt-out problem—the likelihood of citizens opt out of receiving certain types of alerts or stop paying attention to alerts delivered to their phones—by increasing the relevance of the messages to the recipients. Once the phone makes a positive delivery decision by matching the recipient's location with the geo-target embedded in the alert, a straightforward approach would be to simply show the recipient's location relative to the geo-target together with the alert text. Other local, contextual information, such as the proximity of the recipient to the danger zone or the recipient's location history (recently, frequently, or regularly visited locations) could also be taken advantage of to influence the delivery decision and improve alert relevance further.

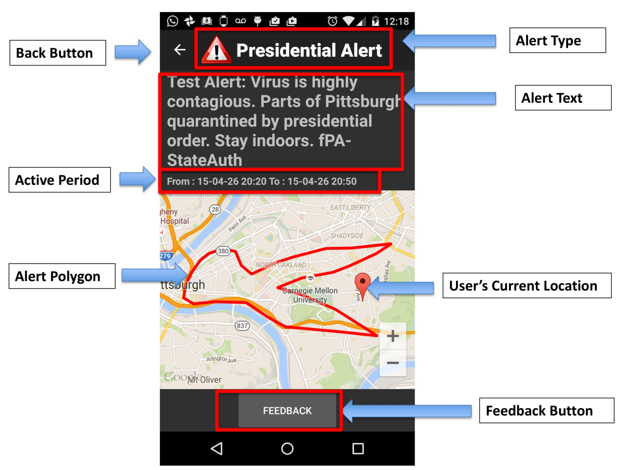

Fig. 2: Sample WEA+ Alert Augmented with a High-Information Map

Based on the above ideas, we proposed, developed, and evaluated a variety of enhancements to the WEA service. These enhancements were aimed at improving the effectiveness of geographically targeted emergency alerts and built using a flexible test bed and experimental framework, called

WEA+. The test-bed allowed us to deploy the envisioned WEA enhancements and assess their effectiveness with more than 225 subjects under simulated emergency situations. A sample WEA+ message is shown in Fig.2. By comparing the subjects' responses to alerts sent with and without the enhanced features, we quantified the perceived value of each tested feature. Such live testing of potential WEA improvements in a realistic setting with human users is a unique aspect of our work, and, to our knowledge, constitutes the first WEA study of its kind.

II. Related Work

Previous work on possible WEA improvements include a comprehensive study of WEA integration considerations by Software Engineering Institute (SEI) researchers [2], who posited that the ubiquity of smart phones enable novel technical solutions both for improved geo-targeting and for addressing other current WEA limitations. The importance of accurate geo-targeting was also reiterated in several other reports. The Department of Homeland Security's (DHS)'s WEA service recommendations [3] and SEI's WEA best practice recommendations [1] conjecture that alert originators will use the WEA service more extensively if alert messages can be better targeted to the size and location of the geographic region impacted by the emergency event.

The WEA service currently supports only text messages (see Figure 1). The 2013 DHS report [3] recommended that WEA should also support richer media content in alerts, including both maps and other rich media forms such as images and audio. Inclusion of such artifacts could convey more information to the public about the situation and the required action. A recent study by University of Maryland's National Consortium for the Study of Terrorism and Responses to Terrorism [4] concluded that inclusion of a high-information map specifying the alert region and the recipient's location could have a significant and positive effect on public response outcomes including interpretation and personalization, with a potential to improve protective action-taking.

With respect to geo-targeting granularity, Nagele and Trainor [5] stated that being able to set an appropriate polygon size could be an important factor in improving public response to alerts. However, this approach would be useful only if the actual delivery mechanism respects the finer resolution of smaller targets, which we can ensure with client-side filtering.

III. WEA+ Test-bed

CMU's WEA+ Test bed is a complete and flexible experimental platform to implement, deploy, and test potential WEA enhancements. It consists of (1) an alert creation subsystem with a web-based user interface for designing and scheduling WEA alerts with and without enhancements; (2) a mobile application for receiving alert messages with various enhancements and for allowing the recipients to provide feedback; and (3) a backend server to store the scheduled alerts and the data collected from users and to push any scheduled alerts to smart phones running the mobile application.

The architecture of WEA+ is illustrated in Fig. 3 together with the technologies used in implementing the various components. In the figure, Alert Repository, Feedback Database (DB), and the central component constitute the backend server, the WEA+ App is the mobile application, and the Control Center, with a user interface running on an alert originator's computer, constitutes the alert creation subsystem.

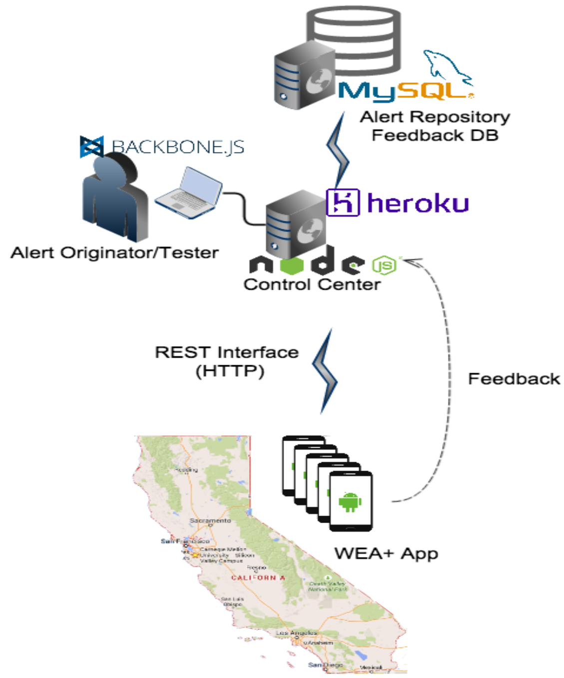

Fig. 3: Architecture of WEA+ Testbed

Fig. 4 illustrates the user interface of the alert creation subsystem, which runs on a web browser to create, schedule, and manage alert messages, define and add polygon-shaped geo-targets to them, and define subject groups for the scheduled alerts for A/B-style testing.

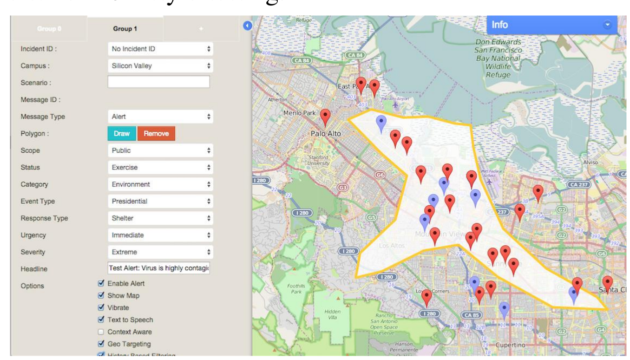

Fig. 4: The User Interface of the Alert Creation Subsystem.

Finally, Fig. 2 gives an idea of the additional functionality supported by the WEA+ mobile application over the current built-in WEA capability of smart phones. The screen-shot depicts an alert augmented with a high-information map. The map shows the alert's region, or geo-target, as described by a polygon, the user's (phone's) location, and the active period of the alert. When the alert has the geo-targeting feature turned on, the app filters out the alert as long as the user is outside the geo-target and does not enter it during the alert's active period.

IV. Experiment Design and Analysis

The main research goal of the experiments conducted during two WEA+ trials was to evaluate whether certain improvements to the WEA service would make it more effective for the public. We also evaluated certain alert characteristics, such as message length and timing, as well as overall impressions about WEA after exposure to many alerts. However, we do not discuss these aspects here. We focus on three main enhancements evaluated: inclusion of high-information maps, precise geographical targeting using on-phone geo-filtering and location-history-based targeting. Other enhancements evaluated, such as the use of a digest view related to a stream of connected alert messages [6], use of text-to-speech, location prediction, and inclusion of external links, are discussed in the full technical report [7].

First we briefly explain each of the three enhancements tested. Then we explain the experimental design used for testing these enhancements, followed by the analysis approach.

A. Enhancement 1—Inclusion of High-Information Maps

If a representation of an alert's geo-target can be encoded and sent with the alert text to the users, the recipient's phone, if capable of doing so, can easily display a map of the alert area showing the alert region (in our case a polygon) and the location of the recipient. Hamilton et al. [4] refer to such maps as high-information maps. We compared alerts displaying a high-information map to those that did not (as in the normal WEA service).

B. Enhancement 2—Geo-filtering

Most modern phones are equipped with a good consumer-grade GPS receiver and Wi-Fi capability. Built-in location services can determine the geographic location of the device with reasonable accuracy by combining information from these two sources. If the geo-target specifying the alert region is embedded in the broadcast alert payload, alert messages can be filtered on the device by the mobile application by checking the device location against the alert region. We refer to this client-side feature as geo-filtering. Geo-filtering effectively reduces the dependence on wireless carriers to control geo-targeting precision. We compared responses to geo-filtered alerts with those that were not geo-filtered.

C. Enhancement 3—Location History

The WEA+ mobile application regularly recorded the geo-locations of the users' phones. This capability resulted in a local location history for each user. When a geographically targeted alert was sent with the location history feature turned on, the mobile application used the local location history on the phone to determine if the recipient had ever visited the alert region using the geo-target polygon embedded in the alert. If the recipient had visited the alert area in the past, the alert was shown; otherwise it was discarded. We compared geo-filtered alerts with and without the location history feature turned on. The location history feature can be implemented on the user's device while respecting the user's privacy since location data is not sent outside and all filtering is performed locally.

D. Experimental Design

To test the above enhancements, two experiments were conducted with 140 subjects using an Android version of the WEA+ mobile application. These experiments were conducted in two locations during two trials, which included a third experiment not reported here. The remainder of the 225 subjects were iOS users who participated in this third experiment on evaluating situational awareness.

The two experiments were similar and used the same single-factor, randomized repeated-measures design. The single factor was binary, representing either the control (Group A) or a tested enhancement feature (Group B). The experimental design used is illustrated in Fig. 5.

Multiple alerts were sent over multiple days, corresponding to fictitious, but realistic emergency situations. During the first experiment conducted in Silicon Valley, 24 alerts were issued to a total of 52 subjects over eight days. During the second experiment, 54 alerts were issued to a total of 88 subjects in Silicon Valley and Pittsburgh, again within a span of eight days.

Each issued alert had two variations for A/B-style testing of the differences between the variations. Subjects were evenly and randomly divided into Group A and Group B. A standard (or control) alert was sent to subjects in Group A and a variation, i.e., an enhanced alert with a predetermined tested feature, was sent to subjects in Group B. Group A subjects received the control alert and Group B the enhanced alert with the tested enhancement feature.

After each alert, the WEA+ mobile application allowed the subjects to provide feedback on the last-received alert by answering a set of multiple choice questions on their phones (see Fig. 6 for an example screenshot) to assess a set of outcomes for the tested feature relative to the control group. We evaluated these outcomes to quantify the effectiveness of the enhancements tested. The outcomes were: (a) *Understanding*: Was the alert easy to understand? (b) *Relevance*: Was the alert relevant to the recipient given the recipient's context? (c) *Annoyance*: Would the alert annoy the recipient in a similar real emergency situation? (d) *Actionability*: Would the alert prompt the recipient to take protective action in a similar real emergency situation? (e) *Milling Behavior*: Would the alert encourage the recipient to seek confirmation from alternative sources? (f) *Adequacy*: Does the alert contain sufficient information for the recipient to assess the situation? (g) *Usefulness*: Would the recipient find the alert useful in a similar real emergency situation?

E. Data Analysis Approach

The outcomes were assessed on a nominal scale, making a frequency-based analysis appropriate. We therefore used the standard Chi-square independence test for all tested enhancements (with the null hypothesis that the tested enhancement is independent of the response distribution) [8].

In all Chi-square tests, the selected alpha level was 0.05. Thus we considered a test result to be significant when the p-value was below 0.05, rejecting the underlying null hypothesis.

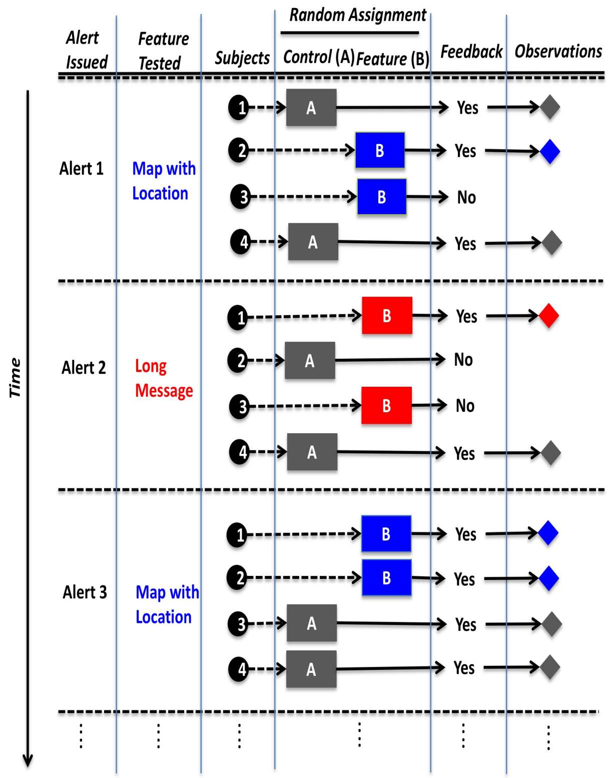

Fig. 5: Depiction of the Experimental Design to Test WEA Enhancements

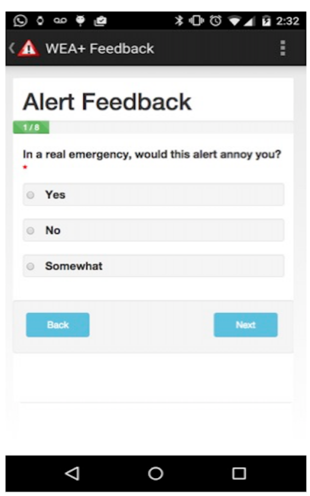

Fig. 6: Sample Feedback Question Sent Along with Every Alert

We measured effect size in two different ways: (1) theoretical, using Cramer's V (C.V) statistic and (2) practical, using odds ratio (O.R.) [9]. Given the underlying degrees of freedom, the theoretical effect sizes were interpreted as follows [9], [10]: (a) Very small: C.V smaller than 0.1; (b) Small: C.V larger than or equal to 0.1 and less than 0.3; (c) Medium: C.V larger than or equal to 0.3 and less than 0.5; and (d) Large: C.V larger than or equal to 0.5.

An effect size between 0.2 and 0.3 as measured by C.V is considered normal in studies dealing with human behavior where outcomes might be affected by multiple uncontrolled factors [10].

We first analyzed the results individually for each experiment. Then we performed a pooled analysis by combining the data from both experiments. In the next section, we report on the pooled results from the two experiments.

V. Results, Limitations, and Conclusions

A. *Alerts with High-Information Maps*

Based on analysis of the subjects' feedback (see Table 1), we found that alerts that display high-information maps increase the relevance of the alerts to the recipients. The improvement was significant. The magnitude of the improvement was theoretically small according to C.V, but according to O.R., a more practical effect size measure, maps improved the odds of finding an alert relevant considerably (by 75 percent). When asked explicitly whether they found the map displayed with the alert just received useful, subjects overwhelmingly responded that they did. This result was highly significant, and further supported and strengthened by the final questionnaire responses. We conclude that High-Information Maps have a positive effect on the relevance of an alert conditional on the recipient's location and situation, and are a highly desired WEA enhancement feature. Maps also appear to affect the information content of alert messages, as measured by adequacy. The improvement is both smaller and subtler than that for relevance, however.

We did not find any evidence of a positive or negative effect of high-information maps specifically on actionability, annoyance, and milling behavior.

B. *Alerts with On-Phone Geo-Filtering*

Precise, fine-grained geo-filtering on the phone improved alert relevance to recipients as hypothesized (see Table 2). The improvement was highly significant with a near-medium theoretical effect size as measured by C.V and considerably large practical effect size as measured by O.R. (over three times improvement in the odds). Actionability was also better with geo-filtering, but this effect was not as strong. We conclude that Geo-Filtering has a significantly positive impact on alert relevance and a small to moderate impact on actionability.

C. *Alerts Filtered with Location History*

We expected filtering an alert based on the recipient's Location History to improve an alert's relevance to recipients. The improvement (see Table 3) was highly significant with a near-medium theoretical effect size as measured by C.V (0.25) and considerably large practical effect size as measured by O.R. (335 percent, or over four-fold improvement in the odds). Actionability and adequacy also improved when geo-filtering was combined with location-history-based filtering. We conclude that Location History is a highly desirable enhancement and is likely to strengthen the positive impact of Geo-Filtering, in particular on alert relevance and actionability.

Table 1: Results for Alerts With and Without Maps

Experiment	Tested Enhancement Feature : Map with User's Location					
H_0: Measured level of outcome construct is independent of inclusion of a map showing geo-target and location. H_1: Alerts with maps showing geo-target and location improve the measured level of outcome construct.						
Answer	**Freq.**		**Chi-Sq.**	**Rej. H_0?**	**Effect Size**	
	0	1			C.V.	Odds R.
Understanding: Did you understand this alert message?						
No	26	12	4.35	**No**	0.07	1.64
Partially	29	16				
Yes	425	355				
Total	480	383				
Relevance: In a real emergency, would this alert be relevant to you given your situation and location?						
No	134	97	13.34	**Yes**	0.13	1.49
Not Sure	74	29				
Yes	269	243				
Total	477	369				
Annoyance: In a real emergency, would this alert annoy you						
No	310	252	0.06	**No**	0.01	0.98
Somewhat	67	52				
Yes	92	73				
Total	469	377				
Actionability: In a real emergency, would this alert prompt you to take action?						
No	152	124	0.46	**No**	0.02	1.03
Not Sure	88	63				
Yes	230	185				
Total	470	372				
Milling Behavior: In a real emergency, would this alert prompt you to seek further information?						
No	127	77	0.43	**No**	0.02	0.90
Not Sure	71	43				
Yes	279	153				
Total	477	273				
Adequacy: Did this alert contain enough information?						
No	125	39	15.86	**Yes**	0.15	1.63
Not Sure	44	32				
Yes	285	195				
Total	454	266				

Table 2: Results for Alerts With and Without Geo-Filtering

Experiment	Tested Enhancement Feature : Alerts with Geo-Targeting					
H_0: Measured level of outcome construct is independent of whether the alert was precisely geo-targeted or not. H_1: Alerts that were precisely geo-targeted improve the measured level of outcome construct.						
Answer	**Freq.**		**Chi-Sq.**	**Rej. H_0?**	**Effect Size**	
	0	1			C.V.	Odds R.
Understanding: Did you understand this alert message?						
No	20	03	3.06	**No**	0.08	2.30
Partially	16	02				
Yes	300	96				
Total	336	101				
Relevance: In a real emergency, would this alert be relevant to you given your situation and location?						
No	126	11	31.20	**Yes**	0.27	4.12
Not Sure	44	09				
Yes	163	79				
Total	333	99				
Annoyance: In a real emergency, would this alert annoy you						
No	212	74	04.67	**No**	0.10	0.77
Somewhat	50	08				
Yes	66	16				
Total	328	98				
Actionability: In a real emergency, would this alert prompt you to take action?						
No	127	25	6.90	**Yes**	0.13	1.75
Not Sure	55	16				
Yes	147	58				
Total	329	99				
Milling Behavior: In a real emergency, would this alert prompt you to seek further information?						
No	122	28	0.70	**No**	0.04	1.21
Not Sure	47	12				
Yes	164	47				
Total	333	87				
Adequacy: Did this alert contain enough information?						
No	85	13	4.33	**No**	0.10	1.62
Not Sure	28	08				
Yes	206	62				
Total	319	83				

D. Conclusions

In summary, inclusion of High-Information Maps, precise geographical targeting through client-side Geo-Filtering, and leveraging the user's Location History in making the alert delivery decision were all found to be high-value features. These features have the potential to improve the effectiveness and acceptance of the WEA service by the public.

In particular, relevance was significantly impacted in all three cases. Actionability, which is associated with safety and preventive response, was impacted by Geo-Filtering and and Location History.

Therefore, we recommend that these enhancements be given serious consideration in the future versions of the WEA service.

E. Limitations

Convenience sampling poses the main threat to the external validity of the results. The subjects who participated in the user experiments were volunteers who were recruited from two Carnegie Mellon University campuses. They were predominantly technology savvy and comfortable using their smart phones' advanced capabilities. Therefore there is a risk that their responses to technology-based features may differ from those of the average citizen. Also self-selected volunteers

Table 3: Results for Alerts With and Without Location History

Experiment	Tested Enhancement Feature : Alert with Location History					
H_0: Measured level of outcome construct is independent of whether the alert was sent to users who frequently visit the geo-targeted area or not. H_1: Alerts that are targeted to recipients who frequently visit the geo-targeted area or have moved in the geo-targeted area improve the measured level of outcome construct.						
Answer	Freq.		Chi-Sq.	Rej. H_0?	Effect Size	
	0	1			C.V.	Odds R.
Understanding: Did you understand this alert message?						
No	7	5	0.45	**No**	0.03	0.78
Partially	6	3				
Yes	256	123				
Total	269	131				
Relevance: In a real emergency, would this alert be relevant to you given your situation and location?						
No	92	16	24.57	**Yes**	0.25	3.35
Not Sure	24	08				
Yes	153	106				
Total	269	130				
Annoyance: In a real emergency, would this alert annoy you						
No	178	92	1.25	**No**	0.06	1.00
Somewhat	37	13				
Yes	53	26				
Total	268	131				
Actionability: In a real emergency, would this alert prompt you to take action?						
No	98	25	14.28	**Yes**	0.19	2.19
Not Sure	39	17				
Yes	131	88				
Total	268	130				
Milling Behavior: In a real emergency, would this alert prompt you to seek further information?						
No	89	30	5.19	**No**	0.11	1.64
Not Sure	34	14				
Yes	147	86				
Total	270	130				
Adequacy: Did this alert contain enough information?						
No	32	31	9.28	**Yes**	0.15	0.56
Not Sure	20	08				
Yes	209	88				
Total	261	127				

tend to be more motivated than the general population. As an alleviating factor, selection bias applies equally to the two compared groups in an internally randomized design, which was the case in both trials.

The experiments relied on suspension of disbelief and alerts send under artificial emergency scenarios. People may behave differently in real-world situations when faced with real dangers to their safety and to their property. Short of staging actual emergencies or deceiving the subjects—neither of which would be safe—we cannot entirely eliminate such threats in a controlled study. In the post-trial questionnaire, over two-thirds of the subjects found the level of realism in the test alerts acceptable.

The outcomes were evaluated via self-assessment based on the subjects' responses to a set of questions posed after receiving each test alert. Therefore we evaluated the perceived value of the tested enhancements with respect to a set of pre-determined constructs. Although the outcomes were not validated by other, more objective means, we believe perceived value to be a relevant and important consideration for public adoption and acceptance of the WEA service.

VI. Acknowledgments

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